5.2

Visual-Vestibular Integration Motion Perception Reporting

(DSO 604 OI-1)

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BACKGROUND

Our perception of how we are oriented and moving is dependent on the transduction and integration of sensory information from visual, vestibular, proprioceptive, somatosensory, and auditory systems. Attention levels and expectations about position and movement also influence perception. Perceptual errors are most commonly due to one or more of the following: (1) limitations of sensory modalities in transducing position and motion information from environmental stimuli, particularly inertial and visual, (2) loss of information from one or more of the sensory modalities due to pathology or absence of an effective stimulus, and (3) incorrect integration of multimodal sensory signals. Illusory self-orientation, self-motion, and visual scene or object motion are evidence of perceptual errors. Almost 200 years ago, Purkinje [1] wrote of how perceptual errors provide insight into the mechanisms underlying perceptual and sensorimotor functions that make normal performance possible.

Perceptual errors may lead to inappropriate motor commands to control systems involved in eye-head, eye-hand, eye-head-hand coordination, and postural and locomotor stability. The effects of perceptual errors cover a wide range and can be: (1) merely interesting or fun, such as illusions of self-motion produced by large screen cinemas, (2) annoying, as with reaching errors and knocking objects on the floor or unnecessary postural adjustments, (3) severely inappropriate postural adjustments, resulting in falls and physical injury, or (4) inappropriate control of a vehicle, such as a car or aircraft, resulting in serious injury or death. Perceptual errors are considered to be the primary cause of approximately 10% of fixed wing and helicopter military accidents, and for approximately 35% of all general aviation fatalities [2].

The absence of an effective gravity vector in spaceflight rearranges the relationships of signals from visual, skin, joint, muscle, and vestibular receptors, initiating adaptive changes in sensorimotor and perceptual systems. Return to Earth normal gravity requires readaptation. Adaptation occurs as the result of sensory compensation and/or sensory reinterpretation. In the absence of an appropriate graviceptor signal during spaceflight, information from other spatial orientation receptors, such as the eyes, the vestibular semicircular canals, and the neck position and somatosensory receptors, can be used by astronauts to maintain spatial orientation and movement control. Alternatively, signals from graviceptors may be reinterpreted by the brain. On Earth, otolith signals may be interpreted as linear motion or head tilt with respect to gravity. Because stimulation from gravity is absent during spaceflight, interpretation of the graviceptor signals, such as tilt, is inappropriate. Therefore, during adaptation to microgravity the brain reinterprets all otolith graviceptor inputs to indicate translation. This is the otolith tilt-translation reinterpretation (OTTR) hypothesis [3, 4].

A spatial orientation perceptual-motor system that is inappropriately adapted for the inertial environment can lead to spatial disorientation, motion sickness, and errors during: (1) spaceflight activities, such as visual capture of operationally relevant targets, switch throws, satellite capture, object location, and manipulation of objects, (2) entry, such as acquiring information from instrumentation, switch throws, activities requiring eye/head/hand coordination, attitude control procedures, pursuit of a moving object, and pursuit and capture of visual, tactile, or auditory targets, and (3) nominal egress activities, such as visual target acquisition, pursuit of a moving object, and emergency egress. The risk of operational performance errors and motion sickness is thought to be related to prior spaceflight experience, flight duration, and circumstance, such as unusual Orbiter attitude, smoke, darkness, or crew complement. The transition between microgravity and Earth, when the perceptual and sensory motor systems are inappropriately adapted to the inertial environment, poses potential risks to space travelers. Therefore, the development of countermeasures for these disturbances was important to EDOMP.

Detailed Supplementary Objective (DSO) 604 Operational Investigation-1 (OI-1) was conducted to investigate the following hypotheses:

1. Adaptation to microgravity and readaptation to Earth normal gravity is indicated by the initial appearance

and gradual resolution of motion sickness symptoms and perceptual illusions of self/surround-motion produced by voluntary head/body movements during spaceflight and after return to Earth.

2. Vision and/or tactile cues attenuate the illusory self-motion associated with voluntary head/torso movements during spaceflight and upon return to Earth.

3. Adaptation to microgravity is revealed initially by reliance on visual scene orientation cues and subsequently by reliance on internally generated orientation cues.

4. Postflight motion sickness, perceptual disturbances, and readaptation time constants increase as mission length increases. These disturbances occur more frequently, are more intense, and take longer to resolve as mission duration increases.

METHODS

Motion perception and motion sickness reports were collected from crew members before, during, and after spaceflight, using a standardized Sensory Perception Questionnaire [5, 6] and a Motion Sickness Symptom Checklist. These reports included quantitative estimates of perceived self-motion and surround-motion associated with: (1) voluntary head/body movements in flight, during entry and immediately after flight, and (2) exposure to motion profiles in both the Tilt Translation Device (TTD) and the Device for Orientation and Movement Environments (DOME), which are located in the Preflight Adaptation Trainers (PAT) Laboratory at the Johnson Space Center [7]. Verbal descriptions of perceived self/surround-motion were reported during flight, during entry, and at wheels stop using a microcassette voice recorder.

This investigation involved four experiment protocols. Protocols using the TTD-PAT device and the DOME-PAT device were performed before flight for training and data collection, and after flight for data collection. A third protocol, involving voluntary head/torso movements, was performed during flight and immediately after wheels stop at landing. A fourth head movement only protocol was performed during the Shuttle entry phase of the mission.

Education consisted of a 1-hour course on neurosensory functional anatomy and physiology, perceptual processes, perceptual illusory phenomena, spatial orientation disturbances, and a specific vocabulary for describing and reporting perceived self-motion and surround-motion. Perceptual illusory phenomena were demonstrated by exposing crew members to a variety of motion profiles in the TTD-PAT for 30 minutes. Ten of the 18 crew members were also exposed to motion profiles in the DOME-PAT for 30 minutes. Crew members were exposed to the TTD and DOME on two separate occasions before their mission.

Preflight Protocols

Before flight, crew member subjects were: (1) briefed on the purpose and objectives of the investigation, (2) provided with descriptions of the functional anatomy of the vestibular and visual systems, perceptual processes, types of illusory self- and surround-motion, and hypotheses concerning sensory adaptation to microgravity, (3) taught a set of vocabulary terms and the body coordinate system used in describing perceptions of self- and/or surround-motion induced by voluntary head movements or passive motion, (4) provided an opportunity to practice using vocabulary terms used to describe motion perceptions during exposure to a variety of stimulus rearrangements produced by the PAT devices, and (5) provided demonstrations and an opportunity to practice voluntary head/torso movement protocols to be performed during different phases of the mission.

TTD-PAT Apparatus and Protocol

This device was a one degree of freedom (DOF) tilting platform on which the subject was restrained in a car seat. In the pitch configuration, the axis of tilt rotation was approximately aligned with the subject's interaural axis, whereas in the roll configuration the axis of rotation was approximately aligned with the subject's nasooccipital axis. A visual surround, mounted on the platform, moved linearly parallel to the subject's X body axis in the pitch configuration and to the subject's Y body axis in the roll configuration. Surround-motion provided a visual stimulus that translated with respect to the subject. In the pitch configuration, the subject faced the end wall and the surround translated toward and away from the subject. In the roll configuration the subject faced the side wall and the surround translated left and right of the subject. The visual surround was a 2.74 m × 0.89 m × 0.91 m (approximately 9 ft × 3 ft × 3 ft) white box with three-dimensional vertical black stripes on the inside walls and horizontal stripes on the ceiling. Four successively smaller outlined black squares and a solid black square in the center were attached to the inside of the end walls. The line width and separation between lines was progressively smaller from the outer to the inner square to produce the appearance of a tunnel. This tunnel effect produced a visual stimulus distance ambiguity which was designed to allow the subject to scale perceived distance to the walls so that the expanding and contracting optic flow and looming pattern matched the simulated physical acceleration stimulus provided by the tilting base [8]. The linear translation of the visual surround was designed to elicit linear vection (self-motion). The amplitude, frequency, phase, and wave form shape of the tilt base and surround translation were independently controlled by a microcomputer.

Crew members were exposed to four pitch and five roll motion profiles, the order of which was alternated across data collection sessions. The visual surround displacement amplitude was held constant at +/– 60 inches maximum displacement in each direction for all pitch and roll motion profiles. Tilt displacement amplitude for the pitch configuration was +/– 4° with a – 4° rearward offset, and +/– 4° for the roll configuration. Each motion profile was presented for approximately 3 minutes. During exposure to the various motion profiles, crew members were instructed to describe their perceived self-motion and/or surround-motion using the standard vocabulary. The subject was prompted, when appropriate, to ensure that all aspects of the motion were described.

All quantitative estimates of self-motion and/or surround-motion were hand recorded on data spread sheets; and all quantitative and qualitative descriptions of perceived self-motion and/or surround-motion, motion path, visual disturbances, and motion sickness symptoms were voice recorded on a microcassette recorder. Data were subsequently entered onto spread sheets for tabular summary and, where appropriate, statistical analyses.

DOME-PAT Apparatus and Protocols

This device was a 3.7 m (12 ft) diameter spherical dome, with a 1.8 m (6 ft) diameter hole in the bottom. The inner surface was painted white and served as a projection surface for two Triuniplex video projectors with custom wide angle optics. The projectors, along with an adjustable trainee restraint assembly, were mounted on a 1.8 m (6 ft) diameter rotating base that filled the hole in the bottom of the dome. However, rotation was not used in this investigation. The trainee restraint adjusted for positioning the subject to: (1) sit upright, (2) lie on either the left or right side, or (3) lie supine. For the first two positions, the projectors' optical axes were horizontal, and for the supine test, the images were projected on the dome top. The field of view for the trainee was $100° \times 170°$, with 0.1° between adjacent pixels or scan lines. This provided a very wide field of view with moderate to coarse resolution.

The visual data base was a set of polygons representing the visible surfaces in the interior of a closed environment. This was unlike the usual data base for aircraft flight simulators that only represent the outside surface of objects. The operator could select environments and interpretation of trainee controls for different training protocols. The trainee could be placed inside a closed visual environment that represented the Shuttle middeck, flight deck, Spacelab, or a checkerboard room.

A crew member was restrained in the seated upright position and the virtual room was rotated continuously at 35°/second in pitch, roll and yaw with respect to the subject. For pitch, the room moved so that the subject view changed from ceiling to wall to floor to wall to ceiling and so on. For roll, the crew member looked at a wall that rotated in roll with respect to the subject. For yaw, the crew member looked from wall to wall to wall with feet toward the floor. The walls, ceiling and floor of the room were designed in a checkerboard pattern where each surface had a different color of squares alternating with black squares. Polar cues in the virtual room included a door, windows, a printed sign and several stick-man figures standing on the floor. Each rotation axis was presented in the +/– direction with each axis-direction combination presented once in each of three sets of six trials each for a total of 18 trials.

The experiment trials within and across sets were systematically randomized for each crew member. This allowed a unique presentation order for each subject such that each trial followed every other trial at least once, but not necessarily an equal number of times. This was similar to a repeated Latin square design where more than one Latin square was created, and each subject had a dedicated random assignment of systematically randomized trials. The crew member began each trial with eyes closed. Eyes were opened upon instruction from the operator. Using a hand-held event switch, the crew member indicated the following: (1) eyes open, (2) onset of self-motion (vection), and (3) saturation or maximum percent self-motion achieved. The crew member then reported the axis and direction of self-motion, the perceived rate of rotation in degrees/second, percent self- versus percent surround-motion, and if present, the magnitude (in degrees) and direction of paradoxical body tilt. Data were subsequently entered onto spread sheets for tabular summary and, where appropriate, statistical analysis.

The event switch signal was recorded as a square wave using a National Instruments Data Acquisitions Board driven by Data4th software, sampled at 40 Hz. Latency to the onset of self-motion and to maximum self-motion was derived from the event switch signal with a Matlab algorithm script that automatically located the leading edge of the first square wave (indicating eyes open) and calculated the time (seconds) from this point to the leading edge of each of the next two square waves (onset and maximum self-motion, respectively). All crew comments were voice recorded.

Flight Protocol

In the Shuttle middeck, crew members performed voluntary head/torso movements about the pitch, roll, and yaw axes with the axis of rotation being about the waist, and in a feet-to-the-floor orientation. The peak-to-peak head displacement amplitude was approximately 40° and was performed as a step input motion. The crew members, having been instructed to keep their heads aligned with their torsos during all movements to minimize neck proprioceptive inputs, slowly moved to the –20° from vertical position, quickly rotated to the +20° position, and paused until any perceived lag or persistence of motion subsided. The procedure was repeated starting from the –20° position and rotating to the +20° position. Each axis of motion was repeated for three to four cycles, and each set of repetitions was performed twice with the eyes open (EO) and once with the eyes closed (EC). During the eyes open condition, the crew member performed each axis of motion once while fixating on a far visual target (approximately 100 cm) and once while fixating on a near target (approximately 30 cm). All of these conditions were performed once with the feet in restraints and once free floating. Following each axis of voluntary head/torso movements,

and/or surround-motion were recorded in terms of: (1) linear and angular amplitude, (2) velocity, (3) lag (in seconds) between input and output (real-perceived) motion, (4) persistence (in minutes or seconds) of perceived self-motion and/or surround-motion after real motion stopped, (5) directional differences, and (6) the perceived overall motion path. Whenever possible, the head/torso protocols were videotaped.

Shuttle Entry Protocol

During entry, crew members performed +/– 20°, head only, sinusoidal motions at approximately 0.25 Hz in pitch, roll and yaw. Each axis of motion was repeated for three to four cycles, and each set of repetitions was performed once with eyes open while fixating on a visual target, and once with eyes closed. Depending on seat position, the target distance ranged from 2.5 to 3.0 ft (76.2 to 91.5 cm). Following each axis of head movement, perceptions of self-motion and/or surround-motion were recorded as during flight. This protocol was waived for crew members returning on the flight deck.

After Wheels Stop Protocol

Crew members repeated the in-flight voluntary head/torso movement protocol. In some cases, a crew member performed the wheels stop protocol as soon as possible after flight in the Crew Transport Vehicle (CTV) or in the data collection facility.

Postflight Protocol

A videotaped debrief was performed on landing day, with an additional debrief on R+1 or 2 days. The landing day debrief was used to review perceptual experiences associated with the voluntary head movement protocol as well as perceptual experiences not directly associated with the protocol. The debrief performed on R+1 or 2 was used to: (1) clarify descriptions of self- and/or surround-motion recorded in flight and/or during the landing day debrief, and (2) assess perceptual disturbances associated with normal postflight activities. In addition, TTD-PAT and DOME-PAT protocols were repeated after the flight on days R+1 or 2, R+4, and on R+8 if perceptual responses remained different from those recorded before flight.

RESULTS AND DISCUSSION

Perceptions Associated with In-Flight Voluntary Head/Body Movements

The data in Figure 5.2-1 reveal that approximately 70% of the participating astronauts reported illusions of self- and/or surround-motion associated with head/body movements in flight. This value was approximately 80% during entry, and in the early postflight period was approximately 90%. In flight, there were significantly more reports of surround (target) motion than self-motion, associated with both near and far target conditions, whereas during entry and after flight, surround-motion was reported only slightly more often than self-motion (Figure 5.2-1). The strength or compellingness of perceived self/surround-motion was generally reported by crew members to be greatest during entry, somewhat less at wheels stop, much less late in the flight, and the least early in the flight.

Reports of perceived self/surround-motion were more often associated with pitch and roll head movements than with yaw head movements. Of those who reported illusory self-motion, all reported illusory pitch self-motion in flight (far target condition). During entry and wheels stop, there were more reports of illusory self roll motion than pitch or yaw (Figure 5.2-2). When surround-motion was produced by a head movement, crew members frequently reported a perceived lag in the surround-motion of 0.05 to 2.00 seconds and persistence of the motion for 2.00 seconds or more. Crew members reported that smaller head movements tended to produce surround-motion in the same direction as the head movement, whereas larger head movements tended to produce surround-motion in the opposite direction. Perceptions of self/surround-motion during head movements made during flight were described by crew members as stronger and having larger displacement amplitudes when performed under eyes closed and untethered conditions. Larger and/or faster head/body movements were more likely to produce perceptions of self/surround-motion than smaller and/or slower head movements. In general, self-motion and/or surround-motion was reported more frequently during and following medium duration missions compared to short duration missions (Figure 5.2-3).

Crew member descriptions of motion perception illusions associated with voluntary movement provided the information required to develop a useful framework to quantify and categorize motion perception disturbances. Three primary categories of input-output motion perception disturbances were identified: (1) gain (amplitude and rate), (2) temporal (lag and persistence), and (3) path (direction and axis). The most frequent type of disturbance reported both in flight and during the entry/postflight periods was gain disturbance. The most interesting findings were related to temporal disturbances, because three times more temporal lag disturbances were reported during the flight than during the entry/postflight period. However, more than twice as many reports of temporal persistence disturbances were reported during the entry/postflight period than in flight (Figure 5.2-4).

Classification of Individual Astronaut In-Flight Rest Frame of Reference

Previously, two types of astronauts were identified, based on the spatial orientation “resting frame” they adopted [5]. These were: (1) visual-spatial (VS) crew members (50%) who tended to increase the weighting of visual-spatial cues/information to compensate for the absence of a gravitational “down" cue” and (2) internal Z axis (IZ) crew members (42%) who increased the weighting assigned to internally generated Z axis orientation vectors and appeared to ignore visual polarity information, and down was wherever their feet pointed. Eight percent of the crew members weighted VS and IZ information equally.

In the current study, a more systematic approach to rating crew members on the IZ-VS “rest frame” of reference continuum was developed. Transcripts of the two postflight debriefings were analyzed independently by two observers using verbal protocol analysis techniques, to determine the microgravity spatial orientation rest frame of each subject. Each transcript was assigned two scores, one for visual scene versus internal Z axis overall (VSIZO), and the other for visual scene versus internal Z axis time of transition (VSIZT). VSIZO scores were assigned from 1 (primarily internal Z axis) to 3 (primarily visual scene). VSIZT scores, which indicated the time during a mission when the astronaut transitioned from a visual scene to an internal Z axis rest frame, were assigned from 1 (early in flight) to 3 (late in flight or never). Scores were assigned for the purpose of classification.

Transcripts were evaluated using the following VS criteria: (1) rates self as using visual scene rest frame, (2) prefers working in flight in a nominal 1g orientation, (3) greater sense of well-being if 1g orientation is adopted in flight, (4) may perceive self as upside down, sideways, etc. in flight, (5) reports difficulty in switching orientation references and performing coordinate transformations, (6) adopts visual scene as truth, (7) space motion sickness (SMS) disturbances worse with eyes closed, or (8) reports loss of orientation when coming out of airlock. IZ criteria included: (1) self rating as IZ, (2) sense of well-being in any orientation, (3) head defines up, feet define down, (4) easily perceives walls as floor or ceiling, ceiling as floor, etc., depending on current orientation, (5) attributes real self-motion to surround / Orbiter, (6) easily manipulates coordinates (switches references), or (7) reports that the visual scene may be upside down. The data indicate that astronaut perceptual reports can be reliably classified along a VS-IZ dimension. Collapsed across VSIZO and VSIZT ratings, reliability between the people doing the rating was r_s 0.83462; $p < 0.0007$.

In flight there was no difference in the percent of crew reports of self/surround-motion when the rest frame type and mission duration were compared. The one exception was that all of the IZ type astronauts on medium duration missions, but only 25% of the IZ type astronauts on short duration missions, reported self-motion (Figure 5.2-5a). During the entry/postflight period, both IZ and VS type crew members on medium duration missions consistently reported more self-motion and surround-motion than those on short duration missions (Figure 5.2-5b). Finally, VS type crew members on short duration missions tended to report more self-motion and surround-motion than IZ type crew members on short duration missions, in flight and during the entry/postflight period (Figure 5.2-5a and b).

Motion Perception in the TTD-PAT Device

After flight, in the TTD, both IZ and VS type crew members on medium duration missions reported a higher percentage of self-motion than IZ and VS crew members on short duration missions. In addition, postflight in the TTD, VS type crew members on short duration missions reported a much higher percentage of self-motion than IZ type crew members on short duration missions (Figure 5.2-6). Differences in preflight to postflight perceptions of self/surround-motion were generally resolved within four days after landing (R+4).

Overall, asymmetries in perceived angular displacement amplitude right/left (roll) in the TTD were reported much more frequently two days after landing (R+2) than before flight. Also, they were reported significantly more often by VS type than IZ type crew members (Figure 5.2-7). Postflight reports of perceived roll asymmetries were about the same for IZ and VS type crew members on short duration missions. However, IZ type astronauts on medium duration missions reported fewer roll asymmetries postflight than did those on short duration missions. VS type astronauts on medium duration missions reported more roll asymmetries postflight than did those on short duration missions (Figure 5.2-8), suggesting an interaction between spatial orientation type and mission duration.

Finally, in roll configuration the visual surround effectively presented a horizontal, slow optokinetic stimulus. Before flight, crew members never reported visual disturbances, such as blurring or tilting of the stripes or oscillopsia, associated with the stimulus. However, after the flight, there was an average of three reports of visual disturbances across all five profiles (Figure 5.2-9).

Motion Perception in the DOME-PAT Device

Angular vection (self-motion perception) responses were elicited and calculated as described above for the DOME Protocol. Two parameters were calculated: latency to the onset of vection (LOV), and latency to maximum vection (LMV). There were no significant differences in these parameters across axes or between directions within axes. Therefore, all subsequent analyses of variance (ANOVAs) were performed on data collapsed across axes and directions.

Spearman rank order (r_s) correlations were performed to examine the relationship between rest frame of reference and time to transition from VS to IZ, and LOV (Figure 5.2-10). The data indicate that VS-IZ scores were significantly related to vection latencies determined before and after flight (Figure 5.2-11). VSIZO and VSIZT were inversely related to vection onset latency ($r_s = -0.56$; $p < 0.0001$ for VSIZO and $r_s = -0.68$, $p < 0.0001$ for VSIZT). That is, the VS crew members and those who transitioned late or never had shorter latencies to the onset of vection than did IZ crew members.

Both the LOV and LMV were greater for the IZ crew members compared to the VS or the Mixed, which did not differ in latencies (Figure 5.2-12). Similarly, rookies had longer LOV and LMV values than veterans (Figure 5.2-13). Finally, LOV and LMV values were longer for crew members on long duration missions compared to those on short or medium duration missions (Figure 5.2-14).

Table 5.2-1. Evaluation of education/demonstration components of the PAT program

Percent of Crewmembers Reporting Symptom(s)

Symptom	*No Education (N=40)*	*Education (N=18)*	*% Improvement With Education*
Impaired Concentration	23	11.1	51.7
Headache	55	27.7	49.6
Malaise	38	22.2	41.6
Stomach Awareness	65	44.4	31.7
Vomiting	48	38.9	19.0
Nausea	60	55.6	7.3
	Mean:		33.5

Countermeasure Evaluation

Findings from behavioral medicine programs, designed to manage chronic medical disorders, suggest that educational components of the treatment program can lead to some improvement in the patient's condition. Therefore, we predicted that the education and demonstration components of PAT should result in fewer reports of SMS. Motion sickness symptom reports from a group of 14 crew members who participated in OI-1 PAT education were compared with reports from a group of 40 non-participating crew members. The comparison revealed a 33.5% improvement in a group of six SMS symptoms in the educated group (Table 5.2-1). It should be noted that 52.5% of those who received no education and 44.4% of those who received education took anti-motion sickness medication in flight.

SUMMARY

Self-orientation and self/surround-motion perception derive from a multimodal sensory process that integrates information from the eyes, vestibular apparatus, proprioceptive and somatosensory receptors. Results from short and long duration spaceflight investigations indicate that: (1) perceptual and sensorimotor function was disrupted during the initial exposure to microgravity and gradually improved over hours to days (individuals adapt), (2) the presence and/or absence of information from different sensory modalities differentially affected the perception of orientation, self-motion and surround-motion, (3) perceptual and sensorimotor function was initially disrupted upon return to Earth-normal gravity and gradually recovered to preflight levels (individuals readapt), and (4) the longer the exposure to microgravity, the more complete the adaptation, the more profound the postflight disturbances, and the longer the recovery period to preflight levels. While much has been learned about perceptual and sensorimotor reactions and adaptation to microgravity, there is much remaining to be learned about the mechanisms underlying the adaptive changes [9], and about how intersensory interactions affect perceptual and sensorimotor function during voluntary movements.

During space flight, SMS and perceptual disturbances have led to reductions in performance efficiency and sense of well-being. During entry and immediately after landing, such disturbances could have a serious impact on the ability of the commander to land the Orbiter and on the ability of all crew members to egress from the Orbiter, particularly in a non-nominal condition or following extended stays in microgravity [10].

An understanding of spatial orientation and motion perception is essential for developing countermeasures for SMS and perceptual disturbances during spaceflight and upon return to Earth. Countermeasures for optimal performance in flight and a successful return to Earth require the development of preflight and in-flight training to help astronauts acquire and maintain a dual adaptive state. Despite the considerable experience with, and use of, an extensive set of countermeasures in the Russian space program, SMS and perceptual disturbances remain an unresolved problem on long-term flights [11].

Reliable, valid perceptual reports are required to develop and refine stimulus rearrangements presented in the PAT devices currently being developed as countermeasures for the prevention of motion sickness and perceptual disturbances during spaceflight, and to ensure a less hazardous return to Earth. Prior to STS-8, crew member descriptions of their perceptual experiences were, at best, anecdotal. Crew members were not schooled in the physiology or psychology of sensory perception, nor were they exposed to the appropriate professional vocabulary. However, beginning with the STS-8 Shuttle flight, a serious effort was initiated to teach astronauts a systematic method to classify and quantify their perceptual responses in space, during entry, and after flight. Understanding, categorizing, and characterizing perceptual responses to spaceflight has been greatly enhanced by implementation of that training system.

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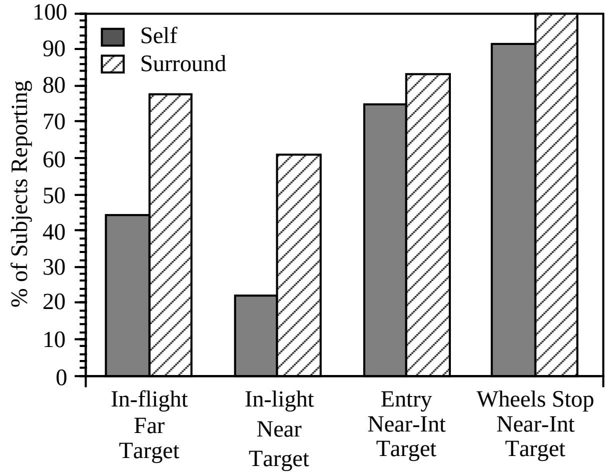


Figure 5.2-1. Percent of astronauts who reported self and/or surround motion associated with making voluntary head/body movements while fixating near and far visual targets in-flight, during entry and at wheels stop.

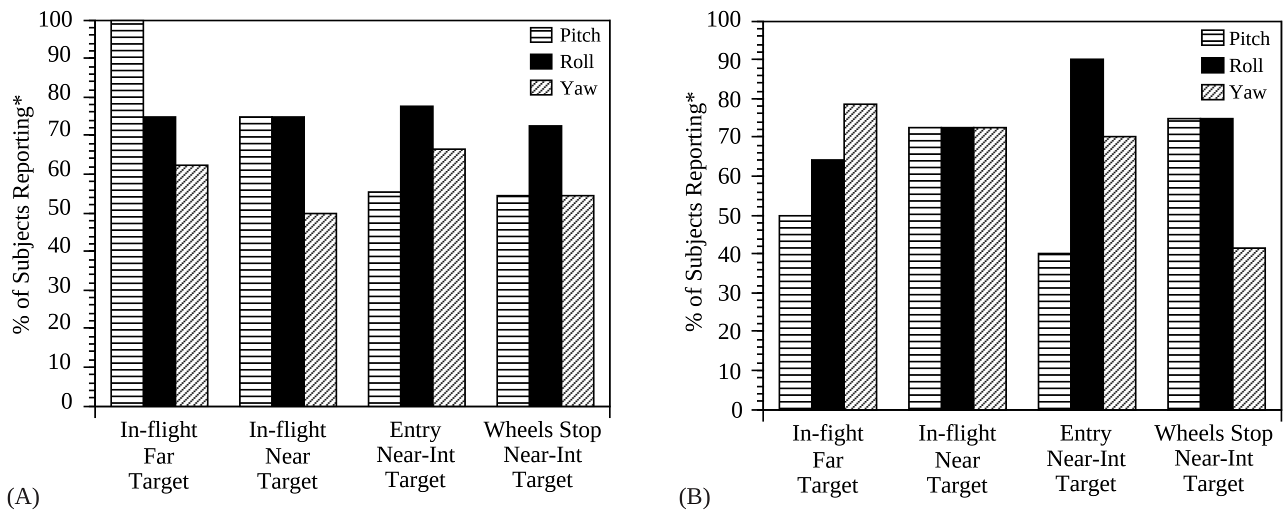


Figure 5.2-2. (A) Percent of astronauts who reported self motion and (B) surround motion associated with making voluntary pitch, roll, and yaw head/body movements while fixating near and far visual targets on-orbit, during entry and at wheels stop.

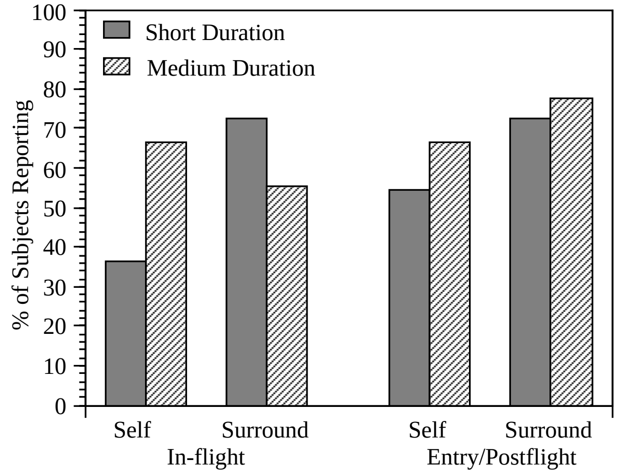


Figure 5.2-3. Percent of astronauts on short and medium duration missions who reported self vs. surround motion associated with making voluntary head/body movements in-flight and during the entry and immediate postflight periods.

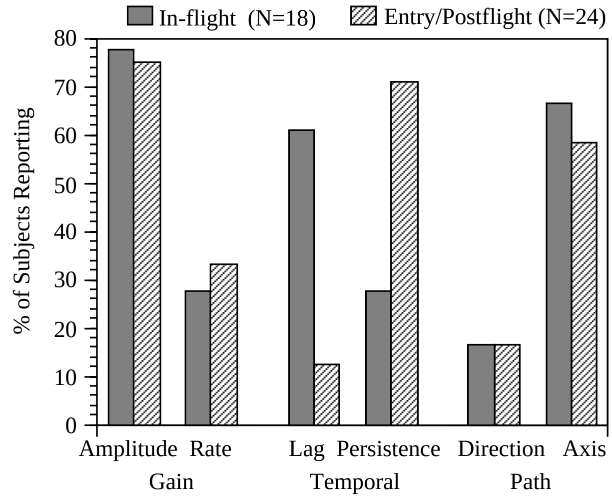
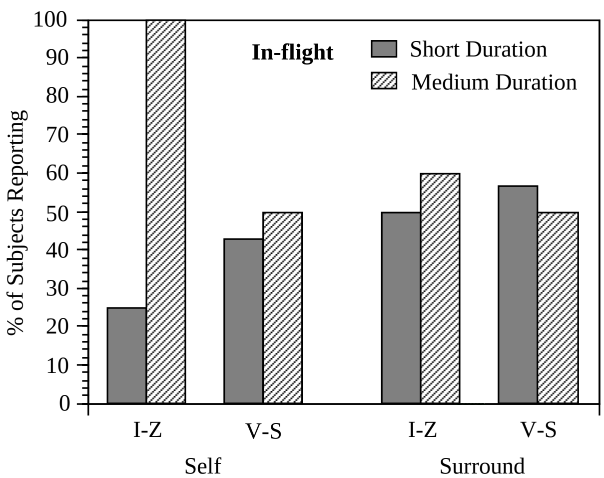
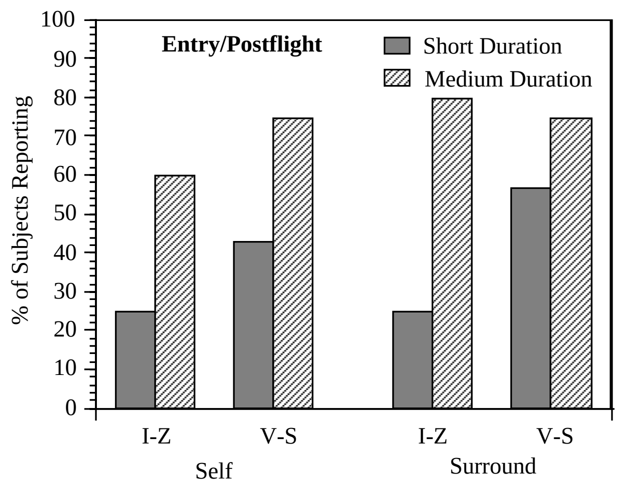


Figure 5.2-4. Percent of astronauts who reported gain, temporal and path input-output disturbances in-flight and during the entry and immediate postflight periods.



(A)



(B)

*Reports associated with voluntary head/body movements while fixating a visual target.

Figure 5.2-5. Percent of internal Z-axis (IZ) and visuo-spatial (VS) astronauts on short and medium duration missions who reported self and/or surround motion (A) in-flight and (B) during the entry and immediate postflight periods.

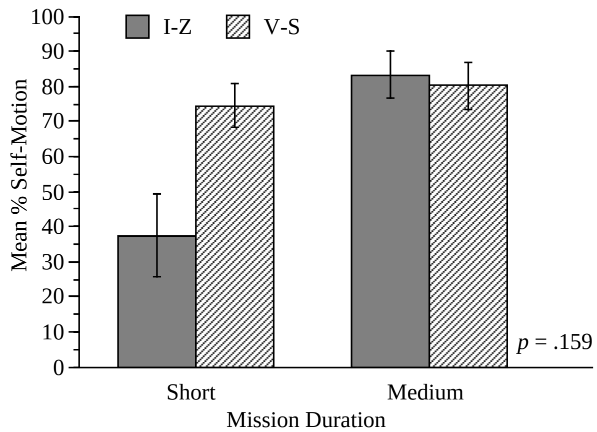


Figure 5.2-6. Percent of self motion in the roll plane postflight, during exposure to the tilt-translation device (TTD), reported by internal Z-axis (IZ) and visuo-spatial (VS) astronauts on short and medium duration missions.

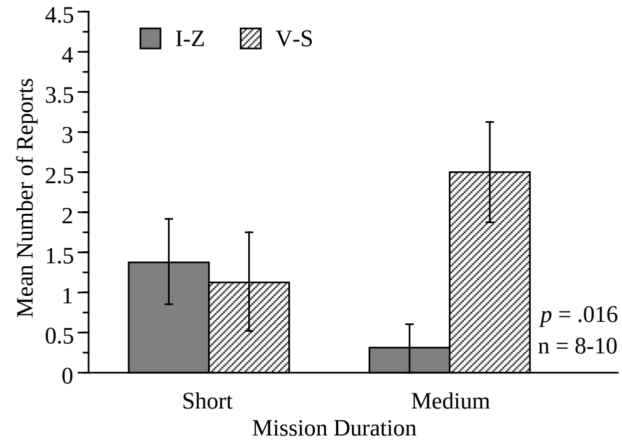


Figure 5.2-8. Average number of reports (across all roll motion profiles in the tilt-translation device [TTD]) of asymmetries in the perceived roll amplitude experienced postflight for the internal Z-axis (IZ) and the visuo-spatial (VS) astronauts on short and medium duration missions.

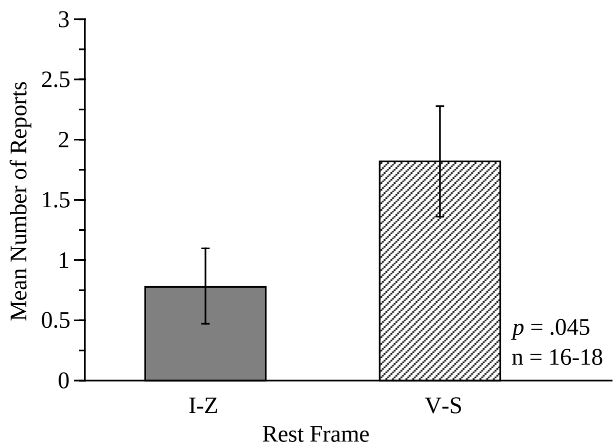


Figure 5.2-7. Average number of reports (across all roll motion profiles in the tilt-translation device [TTD]) of asymmetries in the perceived roll amplitude experienced postflight for the internal Z-axis (IZ) and the visuo-spatial (VS) astronauts.

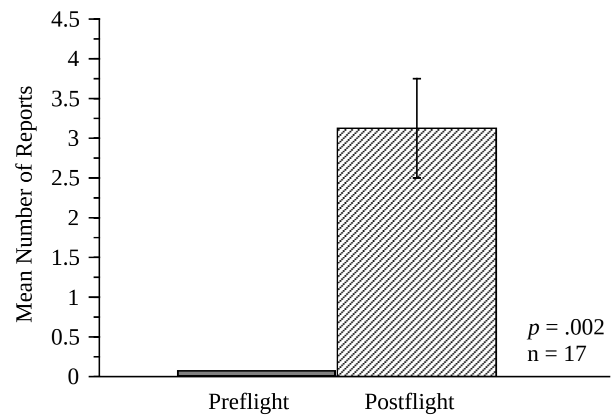


Figure 5.2-9. Average number of reports (across all roll motion profiles in the tilt-translation device [TTD]) of visual disturbances (e.g. oscillopsia, blurring or tilting of the stripes inside the device) preflight and postflight.

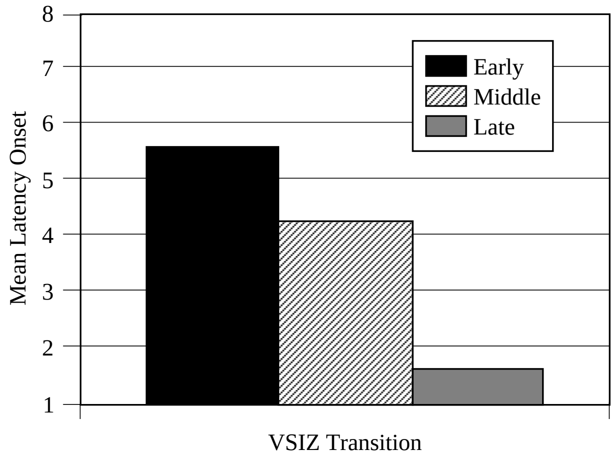


Figure 5.2-10. Mean onset to vection latency (sec) preflight (produced by the device for orientation and motion environments [DOME]) for astronauts who transitioned from a visual to an internal orientation rest frame early, mid and late in-flight.

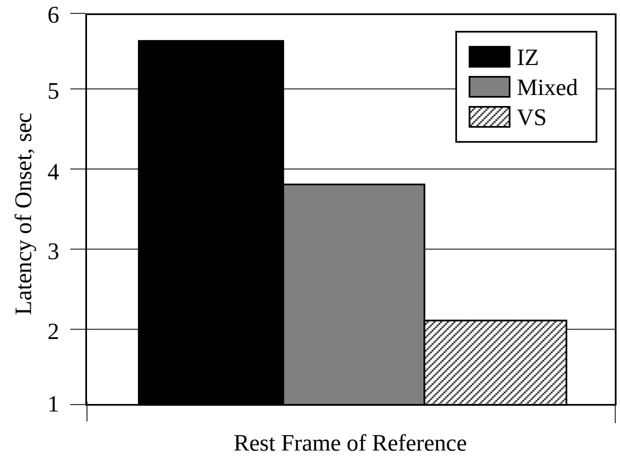
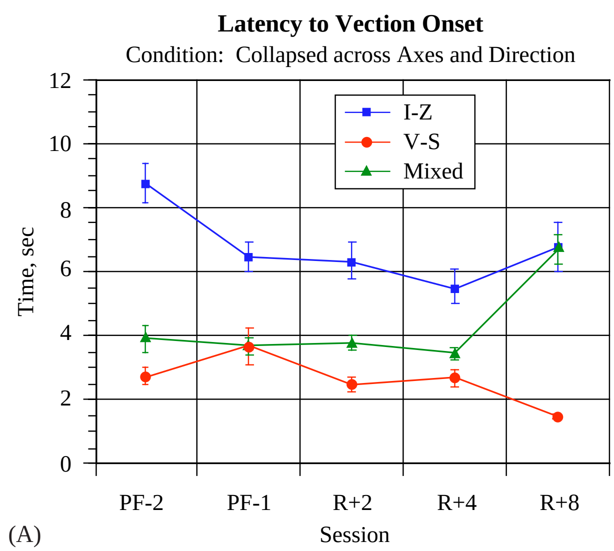


Figure 5.2-11. Mean latency to the onset of vection preflight (produced by the device for orientation and motion environments [DOME]) for the internal Z-axis (IZ), the visuo-spatial (VS) and the mixed rest frame of reference astronauts.



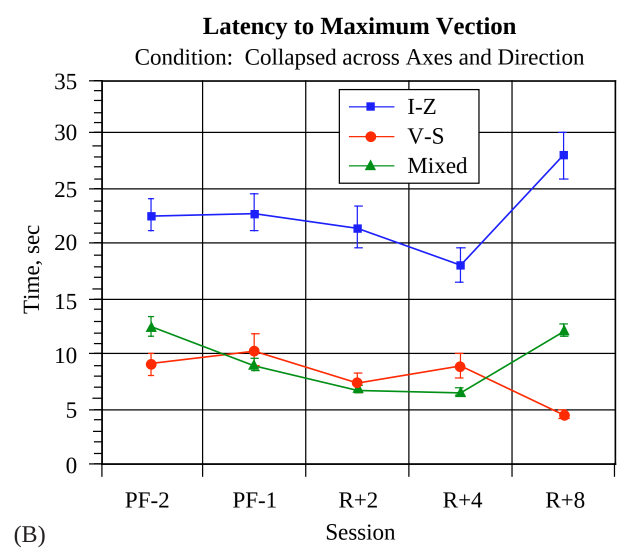


Figure 5.2-12. Mean latency to the onset of vection (A) and to maximum vection (B) preflight and postflight (produced by the device for orientation and motion environments [DOME]) for the internal Z-axis (IZ), the visuo-spatial (VS) and the mixed rest frame of reference astronauts.

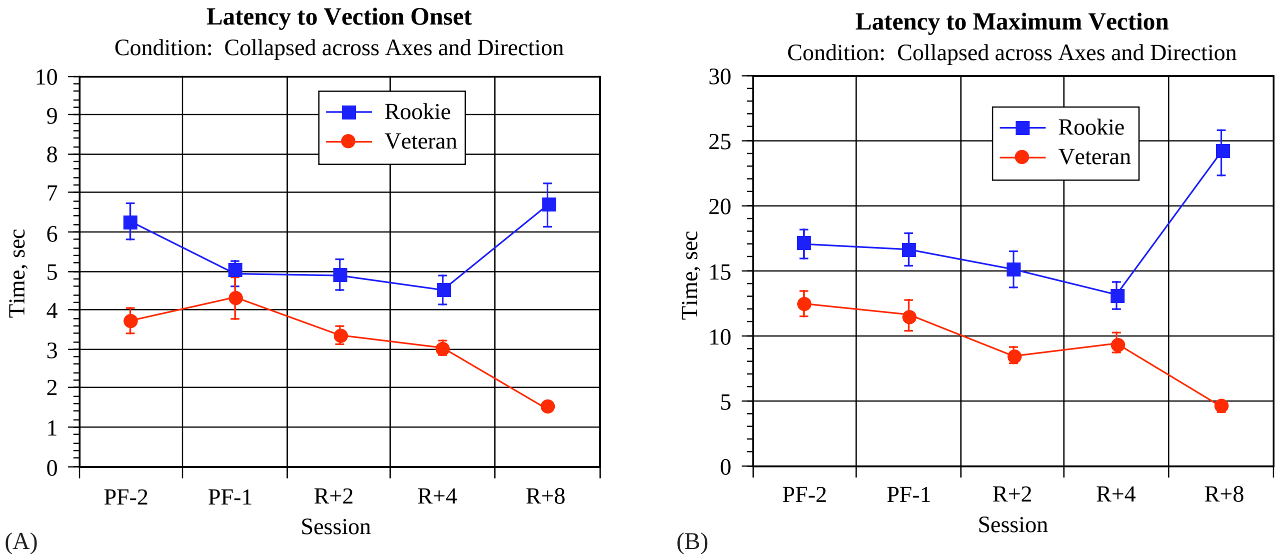


Figure 5.2-13 Mean latency to the onset of vection (A) and to maximum vection (B) preflight and postflight (produced by the device for orientation and motion environments [DOME]) for the rookie and veteran astronauts.

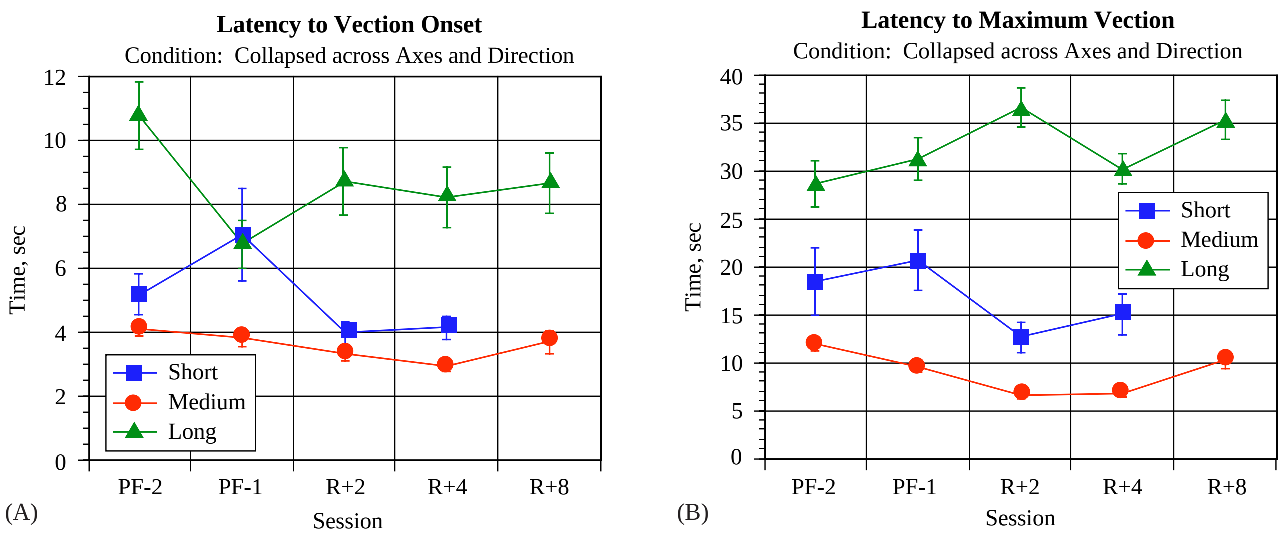


Figure 5.2-14. Mean latency to the onset of vection (A) and to maximum vection (B) preflight and postflight (produced by the device for orientation and motion environments [DOME]) for astronauts on short, medium and long duration missions.